**Greece 2.0**

**Basic Research Financing Action**

**(Horizontal support of all Sciences)**

**Sub-action 1**

**Funding New Researchers**

**PART B2.1**

# Part B2.1 Research Proposal

**Precise oRbit dEtermination and Positioning using sAtellite doppleR obsErvations**

**PREPARE**

* **Principal Investigator** (Name/Surname): **Dimitrios Anastasiou**
* Scientific Area: SA2. Engineering Sciences & Technology
* Scientific Field: 2.1 Civil, Surveying & Architectural engineering
* Scientific Subfield: 2.1.7 Other
* Project Duration (in months): 24
* Total Budget (€): 190 000
* Host Institution: National Technical University of Athens



## Excellence, State-of-the-art and Objectives

### Introduction

Geodesy has greatly advanced since the introduction of artificial, Earth orbiting satellites. A new era has emerged, where satellite-based data dominate the field, providing results for a wide range of geodesy-related fields, including but not limited to positioning, reference frames, altimetry and gravity field determination. Exploitation of satellite-based observations though, is inherently coupled with the complex problem of orbit determination.

Orbit determination offers unprecedented insight in the field of geodesy. Its contribution can be broadly grouped in a twofold role:

1. As a product (i.e. tabulated satellite coordinates and/or velocity) it is needed for most spaced-based applications. Knowledge of satellite position (or state) is a prerequisite for most applications and in general dictates the quality of the application’s outcome. It should be noted that despite the extended demand for accurate satellite coordinates in recent years (mainly due to GNSS), the product list is by no means exhausted here; several other estimates constitute orbit determination products, as are e.g. earth orientation parameters, crucial for reference frame studies.
2. As a field of study, it enables the testing, validation and improvement of models and theoretical aspects for various scientific disciplines, geodesy being the first and foremost beneficiary.

In this project, the second point above is targeted, i.e. the orbit determination methodology, as a means to deliver products of geodetic quality.

Given the composition of the research team and the available resources at hand, we strongly believe the proposal’s aims will be accomplished within the requested period of 24 months. The research team has an extensive, solid background and expertise on space geodesy and especially the analysis of satellite-based observations. It possesses knowledge of state-of-the-art methodologies on data processing and is actively involved in applications of space-geodetic techniques demanding the utmost precision.

### Relevance with the selected Scientific Area

*Please write you text here…*

### Proposal objectives and necessity/challenges

The current proposal's objective is the design and implementation of a state-of-the-art, open-source and free software module to perform precise orbit determination and positioning using the Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS) satellite system.

Within the framework of the project, three satellites will be targeted, namely

* the Joint Altimetry Satellite Oceanography Network – 3 (Jason-3)
* the Sentinel-3A and
* the Hai Yang 2C (HY-2C)

satellites

Via the resulting software, NTUA will be able to provide:

* Precise orbit products for the selected satellite missions.
* High quality position estimates for the DORIS-system ground segment (beacons)
* Estimates for a number of parameters of geodetic and/or atmospheric interest

#### The Jason-3 satellite

Jason-3 is a satellite mission that supports scientific, commercial and practical applications related to sea level rise, ocean circulation, and climate change. It is an international cooperative mission in which NOAA is partnering with the Centre National d'Etudes Spatiales (CNES, France’s governmental space agency), European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), and National Aeronautics and Space Administration (NASA) [1].

#### The Sentinel 3-A satellite

Sentinel-3A is a European Space Agency Earth observation satellite dedicated to oceanography. It will provide, ocean, inland sea and coastal zone color measurements, sea surface temperature measurements and sea surface topography measurements (altimetry) including an along track SAR capability [2].

#### The Hai Yang 2C satellite

The Hai Yang 2C is developed and operated by China. Its mission is to monitor and investigate the marine environment, and obtain marine dynamic environmental parameters including sea surface wind, wave height, sea surface height, etc. HY-2C could directly provide measured data for early warning of disastrous sea conditions and provide services for marine disaster prevention and mitigation, marine rights maintenance, marine resource development, marine environmental protection and marine scientific research [3], [4].

#### Objectives

The objectives of the targeted satellite missions can only be achieved in the presence of high quality space vehicle orbits. Measurements performed by their onboard instruments can only be used in high precision applications, if the satellite's position is known to a required accuracy. Hence, the necessity of precise orbit determination is profound, inherent to the mission's success.

Among other instruments, the payload of the satellites includes DORIS receivers to enable precise orbit determination. However, only a few Analysis Centers worldwide can process observations of this system. According to the International DORIS Service (IDS), the last contribution of the Service to the latest International Terrestrial Reference Frame (ITRF2020, [5]) included analysis results from no more than four Analysis Centers ([6]), each one using their own, in-house software package.

This scarcity of both Analysis Centers and respective software (In comparison, for the other two prominent space-based orbit determination techniques, the International GNSS service includes twelve Analysis Centers [7] and the International ILRS Service includes seven core and a number of Associate Analysis Centers [8]) underlines the need for high-caliber scientific teams targeting this challenging technique, thus further strengthening its contribution to both earth-based (e.g. the ITRF realizations) and space-based (e.g. orbits) products.

On the other hand, this scarcity is also a proof of concept for the challenges posed in performing high quality analysis using the DORIS system. Processing system observations requires expertise in various multi-disciplinary fields (e.g. astrodynamics, geodesy, atmospheric physics, etc), claiming optimal decisions between models and methodologies, design and implementation, in an ever-upgrading field. Precise orbit determination and positioning constitutes one of the most complex and demanding problems in Satellite Geodesy, one that is always evolving due to its multi-disciplinary nature and the ever-growing disposal of satellite missions and data.

### State-of-the-art and Innovation

Currently, only four such software packages exist ([6]) worldwide, but are neither open source, nor free. The objective of the proposed project is to design and implement an orbit determination and positioning software tool using DORIS data, introducing on the way novel approaches, and validating state-of-the-art methodologies. We aim at a robust methodology providing quality satellite state estimates, one though that can be efficient enough to be implemented for near-real time applications. Hence, algorithmic design and implementation, as well as efficiency and resource awareness are all topics to be considered.

We expect that the outcome of the project will be an innovative, state-of-the-art software package, open and free to the scientific community.

Guidelines set by the IDS act as the de-facto standard for orbit determination via DORIS. We will try to comply with this set of recommendations as close as possible, deviating when needed to check and validate alternate or novel processing approaches. Specific points of novelty, will be:

* use of RINEX-only observation files ([12]) (as opposed to the widely used, older doris2.2 format). Allow parsing of near real-time RINEX data parsing.
* use of measured satellite attitude (quaternion-based) determination (as opposed to the common attitude-law approach). According to [9], using measured satellite attitude (satellite body orientation in the quaternion form and solar panel angles) instead of nominal attitude results in slightly better Precise Orbit Determination results
* full compliance with the IERS2010 ([13]) models for transformation between celestial and terrestrial reference frames, including the 2006/2000A precession/nutation models and new mean pole model ([11])
* use of the latest EIGEN time-variable gravity (TVG) models RL04 ([14]) and respective dealiasing products
* use of the newest FES2014/FES2014b ([15]) ocean tide models
* use modern design patterns and implementation details, including template metaprogramming and compile-time mathematical functions (e.g. [16]). Note that most relevant software packages have to be complant with legacy code, written deceads ago, thus prohibiting use of modern programming approaches
* use of a modern, widely used and user-friendly distribution and dissemination approach. Enable software distribution via Docker ([17]), instead of the cumbersome approach of source-code release and building.

### Scientific and social impact

We expect that the results of this proposal will have a strong effect, first and foremost in the scientific community.

The results and outcomes of the project will enhance our knowledge on Satellite Geodesy, Earth and Atmospheric Physics and Orbit Determination/Astrodynamics. Applying state-of-the-art methodologies and novel approaches will greatly enhance the collective knowledge and provide crucial feedback and conclusions. It will reveal drawbacks and limitations and act as a validation platform for the most modern modeling approaches and theories.

Additionally, the community will be provided with a state-of-the-art, free and open software, a fact expected to drive interest and attention to one of the most prominent and robust space-geodetic techniques. Scarcity of such a tool is on of the basic reasons why the system has a more limited user community (as e.g. compared to GPS/GNSS) even though it's application range and accuracy is on the same level.

Via the software tool that will be developed, DSO will be able to contribute to the IDS, thus in turn strengthening the Service's contribution to a series of products vital to the scientific community (e.g. realization of ITRF, Earth attitude, etc). IDS products, as all collective space-geodetic services e.g. the IGS and ILRS, are based on an accumulation of individual Analysis Centers results; hence the Service is in search of top-quality scientific contributors.

DSO itself will also largely benefit from contributing to such a high-caliber Service. IDS is a collective organization of a series of elite institutions, such as the National Centre for Space Studies (CNES), Goddard Space Flight Center (NASA/GSFC), European Space Operations Centre (ESA/ESOC) and Jet Propulsion Laboratory (NASA/JPL). Cooperation and collaboration with such renowned institutions will hugely benefit both the personnel involved (research team) and the NTUA/DSO, gaining unprecedented expertise on the subject.

## Methodology and Implementation

### Research Methodology

Core software development will be performed using the C++ programming language, taking advantage of its speed and versatility. Various minor, peripheral parts of the package will be developed using Python, allowing development speed and ease of use (for end users).

As a first step to tackling the challenges posed in the proposal, the research team will first evaluate and refactor current software tools already designed and developed throughout the previous years (e.g. [18]) and investigate current state-of-the-art models and algorithms to be implemented and incorporated in the software.

Throughout the first year, the research team will design and develop software to handle the complicated modeling of orbital mechanics for Low Earth Orbiting (LEO) satellites. Fundamental forces acting on earth orbiting bodies will be treated using robust, elaborate, state-of-the-art models, describing and compensating for their effects (e.g. atmospheric drag, solar radiation pressure, etc).

Reference frames and time systems (scales), play a major role in the modeling of orbital dynamics. Special care will be taken, to implement the most recent earth attitude models, as described by the International Earth Rotation Service (IERS Standards 2010, [13]). Displacement of reference points (on the Earth's crust) and loading effects (ocean, sold-earth, atmospheric) will be curated using the most recent standards.

Integrators are of fundamental importance in orbit determination, since they allow the (numerical) solution of the equations of motion, accounting for perturbation effects. This system of Ordinary Differential Equations, called the variational equations, plays a crucial role in both the quality and the efficiency of the orbit determination process. We will focus on designing and implementing a multistep integrator, using the Adams-Bashforth-Moulton, Predict–Evaluate–Correct–Evaluate (PECE) algorithm (e.g. [21]).

DORIS system observables (observation equations) will be formulated using the DORIS RINEX format/data files, and following the rigorous approach described in [19]. Novel approaches will be introduced here, estimating the relative frequency offsets using second degree polynomials with process noise.

Once these components are in place and tested, the research team will implement satellite-specific models and parts of the software for the targeted satellites. Attitude determination will be performed using measured data via the quaternion approach when available (at least for Jason-3). If no such data is published, the so called satellite-specific "attitude law" will be implemented to model rigid body rotations. Satellite-specific macromodels ([20]) will be used to compute surface area and on-board phase center eccentricities.

Using the above satellite-specific approach, part of the forces acting on the space vehicle will be refined, using an elaborate modeling of the satellite geometry, attitude and design characteristics. Most notably, drag forces and solar radiation pressure effects will be modeled using this satellite-specific approach.

Parameter estimation will be performed via the (Extended) Kalman Filter algorithm [21]. All parameters describing the satellite state, the orbit and force model dynamics (e.g. atmospheric drag and solar radiation pressure coefficients) and beacon-specific frequency/clock parameters will be estimated, using a sophisticated stochastic approach. Model and observation noise characteristics and their impact on the methodology and respective results will be thoroughly tested.

Lastly, the research team will incorporate the estimation of Earth Orientation parameters (Earth rotation axis pole coordinates and Length of Day) [23] within the analysis process at the level of geodetic precision.

### Work Plan (Work Packages, Gantt Chart, Deliverables and Milestones Table, Table of Risks and Contingency Plan}

#### Brief outline of the overall work plan

During the first three months (WP1), the research team will evaluate and refactor current, already available software developed during the last years within the host institute (e.g. [24] and [25]). This will act as a starting ground for further development.

In WP2, the fundamental parts of the software suite will be designed and developed; all core parts (including orbit dynamics, reference frames, force modelling and integration) of the analysis tools will be implemented in this nine-month span. Depending on the needs, new source code will be written from scratch, or evaluated source code (from WP1) will be adopted and upgraded to meet state-of-the-art standards.

Once the core parts of the software are ready, the research team will start the development of satellite-specific components, including attitude determination and space vehicle macromodels, as well as refinement of the force model to take into account individual satellite geometry (WP3). It is expected that a three-month period of development will be enough for each case.

Shortly after a working version of the software for the first satellite (Jason-3), has been reached, the evaluation process will take place, along with the processing of older (than current), "historic" data (WP4) to obtain results for orbit determination, positioning and other parameters of interest. Bug-fixes and software refinements are expected to take place within this period, which will last until the end of the project.

Once the bulk of the processing results from WP4 is ready, the research team will move on to evaluate and validate the estimated parameters and hence the overall software efficiency (WP5). Position estimates of ground stations in the vicinity of Greece will be accumulated and analyzed to estimate crustal behavior (a task demanding results of utmost accuracy) and compared to times series derived from GNSS analysis (e.g. [26]). Orbital parameters will be validated using the IDS published results (sp3c orbits).

#### Description of each Work Package (WPs)

|  |  |  |
| --- | --- | --- |
| **WP Number: 1** | **WP Title: Refactoring** | |
| **Starting Month: 1** | **Ending Month: 3** | **Person Months (PMs): 4.7** |
| Objectives: Evaluation and validation of already developed software tools by the host institution (e.g. [24] and [25]). Setting of standards, design patterns and development and algorithmic guidelines to be followed later on. Gaining a clear view on the starting ground and further development needs of the core parts of the software. Refactor existing source code to comply to the proposal's needs.  Description of Work: The team will investigate the algorithms and technological development so far, with regard to doppler data analysis. It will explore and study related software and tools. At the end of this working package the standards and specifications for the development software will be decided.  Tasks:  T1.1 - Define software development standards and implementation strategy.  Deliverables:  D1.1 – Software specifications  Milestones:  M1.1 – Software specifications | | |

|  |  |  |
| --- | --- | --- |
| **WP Number: 2** | **WP Title: Core Software Development** | |
| **Starting Month: 3** | **Ending Month: 12** | **Person Months (PMs): 30** |
| Objectives: The research team will design and develop a new, state-of-art, open source, software module to perform precise orbit determination and positioning using the Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS) satellite system.  Description of Work: Design and development of the core part of the new software for doppler observations analysis. In this working package all the necessary algorithms and routines for the processing will be developed and they are independent of the specific satellites.  Tasks:  T1.1 - The first beta version of the software will be developed and released.  Deliverables:  D2.1 – Software release v1.0b1  Milestones:  M2.1 – Software release v1.0b1 | | |

|  |  |  |
| --- | --- | --- |
| **WP Number: 3** | **WP Title: Attitude and phase low implementation** | |
| **Starting Month: 13** | **Ending Month: 20** | **Person Months (PMs): 15.5** |
| Objectives: Upgrade the core software to meet the demands and accuracy of Precise Orbit Determination and Positioning, by implementing individual satellite attitude model, design geometry and macromodels. Derive a state-of-the-art DORIS processing software suite.  Description of Work: Implement space-vehicle attitude determination (either quaternion based if possible or using phase law). Implement satellite-specific geometrical design (e.g. vehicle-fixed reference frame), on-board phase center offset and macromodels. Use the the aforementioned tools to refine satellite force modeling (e.g. computation of projected areas for drag and radiation) and observation modeling (e.g. reduction of observation vectors to receiver phase center). Release software beta versions once satellite-specific modeling is through for each individual satellite.  Tasks:  T3.1 - Implement space-vehicle attitude determination for Jason-3 satellite  T3.2 - Implement space-vehicle attitude determination for Sentinel-3A satellite  T3.3 - Implement space-vehicle attitude determination for HY-2C satellite  Deliverables:  D3.1 – Software Release v1.0b4  Milestones:  M3.1 – Software Release v1.0b2,  M3.2 – Software Release v1.0b3,  M3.3 – Software Release v1.0b4 | | |

|  |  |  |
| --- | --- | --- |
| **WP Number: 4** | **WP Title: Software Testing and Data Processing** | |
| **Starting Month: 16** | **Ending Month: 24** | **Person Months (PMs): 13.5** |
| Objectives: The goal is the validation and evaluation of the software and algorithms implemented in Working Packages 2 and 3. In this Working Package, historic data processing for precise orbit determination will take place in parallel.  Description of Work: The necessary bug fixes and upgrades will be integrated in the software suits. Final release v1.0 will be published. Updates will be based on the results of data processing.  Tasks:  T4.1 - Updates and bug fixes will be integrated into final (v1.0) release of the software suites.  T4.2 - The data will be processed with the software developed in the previous packages. We will also process the data using existing software packages and compare the results.  Deliverables:  D4.1 – Software release v1.0,  D4.2 Results of Data Processing  Milestones:  M4.1 – Validation of Software Release v1.0b1,  M4.2 – Validation of Software Release v1.0b4,  M4.3 – Software Release v1.0,  M4.4 – Data Processing | | |

|  |  |  |
| --- | --- | --- |
| **WP Number: 5** | **WP Title: Validation of geodetic parameters and Time series analysis** | |
| **Starting Month: 21** | **Ending Month: 24** | **Person Months (PMs): 8.4** |
| Objectives: Evaluation and validation of results obtained by the software developed, using products of the utmost quality. Identification of deficiencies and further fine tuning; derive proposals for further enhancements and methodology/algorithmic enhancements. Determination of mismodeling effects or non-mitigated error sources and recommend specific patterns or study areas for their curation.  Description of Work: Stack position estimates derived from the processing of data performed in WP4, to get time-series for DORIS network beacons, in and/or around Greece. Analyze the time-series to derive crustal dynamics (tectonic velocity and harmonics signals if any) on each point and compare with results for GPS/GNSS collocated sites.  Retrieve IDS published orbits (in Sp3c format) and compare with the estimates obtained by the processing in WP4. Compare estimated Earth Orientation parameters to the ones published by the IERS.  Tasks:  T5.1 – Time series analysis for DORIS network beacons  T5.2 - Estimate tectonic velocities and harmonics signals for each station  T5.3 – Compare the results for GPS/GNSS collocated sites  Deliverables: D2.1 – Technical Report WP5  Milestones: M5.1 – Validation of geodetic parameters | | |

|  |  |  |
| --- | --- | --- |
| **WP Number: 6** | **WP Title: Dissemination and communication management** | |
| **Starting Month: 6** | **Ending Month: 24** | **Person Months (PMs): 5** |
| Objectives: Dissemination of project results in the technical and scientific community through presentations, publications and a school/workshop.  Description of Work: Part of the project will be the dissemination of research results and discussion with the scientific community on new solutions and approaches introduced. A website will be developed to promote the project and disseminate the new software. A school/workshop will be organized especially for young researchers in order to learn about the new software and the possibilities that it will provide. Overall, the projects aim to contribute to the development of a research network in Greece and in collaboration with the international scientific community regarding the utilization of the DORIS system. Finally, the results will be presented to the students of the Host Institute (NTUA) or other technical universities.  Tasks: The software will be accessible on a free software repository under an opensource license. Members of the group will participate in two conferences and will write a peer reviewed paper in scientific journal. They will also organize a school/workshop oriented towards young researchers for the presentation of the new software and highlight new possibilities and collaborations.  T6.1 - Website Develop, update and maintain the project website.  T6.2 - Announcements/presentations and publications in scientific conferences Participate in scientific conferences and present the project results and submit papers for publication during the conference proceedings.  T6.3 - Publications in scientific journals: Submit papers in scientific journals  T6.4 - School/Workshop Organization for the dissemination of the project results. Organize and hold the workshop in Athens.  T6.5 - Project Brochure. Prepare a 3-5-page brochure that will include the main results of the project.  Deliverables:  D6.1, D6.2 - Conference presentations,  D6.3 - Peer reviewed paper,  D6.4 - School/Workshop Proceedings,  D6.5 - Website | | |

|  |  |  |
| --- | --- | --- |
| **WP Number: 7** | **WP Title: Project Management** | |
| **Starting Month: 1** | **Ending Month: 24** | **Person Months (PMs): 2.2** |
| Objectives: Technical and financial management of the project. Observing work schedule.  Description of Work: Principal investigator supervises the work flow and financial management of the project. He is in direct contact with the managing authority and the Host Institute responsible for the progress of the project.  Tasks: Project management. Research team supervision. Control over expenditures and compliance with the targeted timetable and Working Plans.  T7.1 - Coordination and financial management of the project Coordinate the project, prepare all required managerial and financial documents, and prepare two intermediate and one final report of the project.  T7.2 - Dissemination of project results.  Deliverables:  D7.1 - Intermediate progress report (1st year)  D7.2 - Intermediate progress report (2nd year)  D7.3 - Final project report | | |

#### Deliverables

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Deliverable Number** | **Deliverable Name** | **Related WP** | **Type[[1]](#footnote-1)** | **Dissemination Level[[2]](#footnote-2)** | **Due Date**  **(in months)[[3]](#footnote-3)** |
| **D1.1** | Software specifications | 1 | R | CO | 3 |
| **D2.1** | Software Release v1.0b1 | 2 | DEM | CO | 12 |
| **D3.1** | Software Release v1.0b4 | 3 | DEM | CO | 20 |
| **D4.1** | Software Release v1.0 | 4 | DEM | PU | 21 |
| **D4.2** | Results of Data Processing | 4 | R | PU | 24 |
| **D5.1** | Technical Report WP5 | 5 | R | PU | 24 |
| **D6.1** | Conference presentation 1 | 6 | DEC | PU | 14 |
| **D6.2** | Conference Presentation 2 | 6 | DEC | PU | 21 |
| **D6.3** | Peer reviewed paper | 6 | DEC | PU | 21 |
| **D6.4** | School/Workshop Proceedings | 6 | DEC | PU | 24 |
| **D6.5** | Website | 6 | DEM | PU | 24 |
| **D7.1** | Intermediate progress report (1st year) | 7 | R | PU | 12 |
| **D7.2** | Intermediate progress report (2nd year) | 7 | R | PU | 24 |
| **D7.3** | Final project report | 7 | R | PU | 24 |

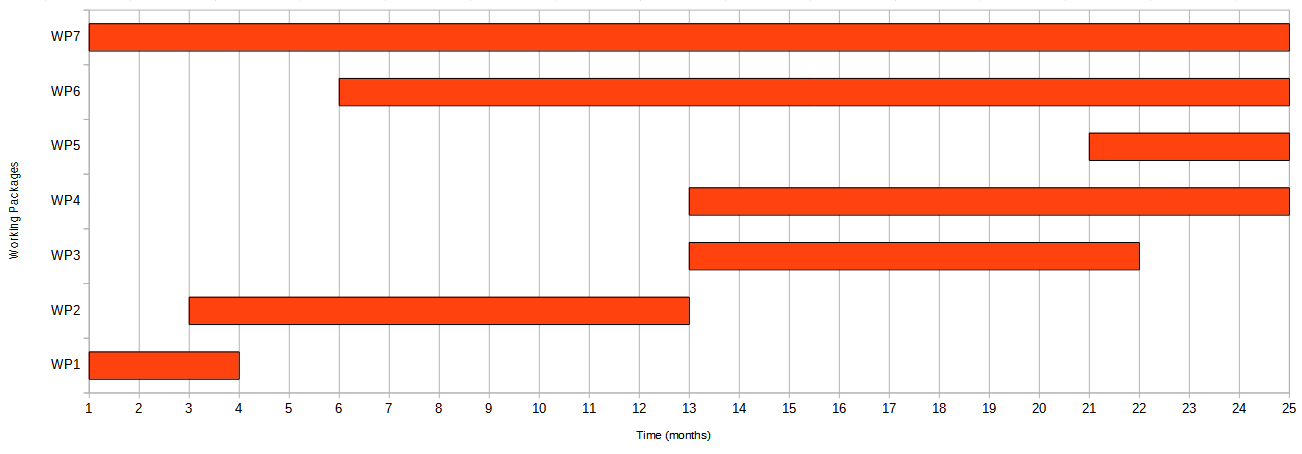
#### Milestones

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Milestone Number** | **Milestone Name** | **Related WP** | **Due Date**  **(in months)** | **Means of Verification** |
| **M1.1** | Software specifications | 1 | 3 | Report |
| **M2.1** | Software Release v1.0b1 | 2 | 12 | Beta Release |
| **Μ4.1** | Validation of Software release v1.0b1 | 4 | 13 | Report |
| **M3.1** | Software Release v1.0b2 | 3 | 16 | Beta Release |
| **M3.2** | Software Release v1.0b3 | 3 | 18 | Beta Release |
| **M3.3** | Software Release v1.0b4 | 3 | 20 | Beta Release |
| **Μ4.2** | Validation of Software release v1.0b4 | 4 | 21 | Report |
| **M4.3** | Software Release v1.0 | 4 | 21 | Release |
| **M4.4** | Data Processing | 4 | 21 | Products |
| **Μ5.1** | Validation of geodetic parameters | 5 | 23 | Report |

#### Risks and Contingency Plan

|  |  |  |
| --- | --- | --- |
| **Description of risk**  (indicate level of likelihood: Low/Medium/High) | **WPs involved** | **Proposed risk –Mitigation measures** |
| **Administrative risk (Low)** | All | Institutional capacity is guaranteed by EU funding |
| **Lost of satellite (Medium)** | 3, 4, 5 | Ιn case of loss of any satellite proposed for attitude and phase low implementation, an alternate satellite of the same mission will be used again if time permits. (e.g Sentinel 6-A against Sentinel 3-A) |
| **Attitude low not successfully determined (Medium)** | 3, 4, 5 | The estimation of precise orbits and positioning will be done with lower precision for the observation of the specific satellite. |

#### Timeline/timetable of the different work packages and their components (Gantt Chart).



### Research Team

Principal Investigator Assistant Professor Dimitrios Anastasiou will be involved in all Working Packages and he will be responsible for managing the project. He will decide on the design specifications of data analysis software. He will participate in code development and validation of the software release, as he has experience in data analysis methodologies. He will be responsible for the design of data processing, validation of geodetic parameters and time series analysis of ground permanent station of DORIS System. Additionally, he will have the technical and financial management of the project and he will participate in conferences and the writing of peer reviewed paper. Finally, he will be responsible for the organization of school/workshop.

Professor Maria Tsakiri Maria specializes in satellite geodesy. He has extensive experience in managing and executing research projects. She will participate in the decision of the software development specifications. She will participate in validation and evaluation of the results for the precise determination orbits and the validation of geodetic parameters. Finally, she will take part in the preparation of the presentations and the peer reviewed article as well as with her experience she will contribute to the management of the project.

Mr. Xanthos Papanikolaou is a PhD candidate specialized in GNSS and DORIS data processing, with software development expertise. He will participate in the design and implementation of the software suites by developing the code and evaluating it. He will handle bug fixes and updates for the software package. He will also take place in data processing and time series analysis of ground stations. He will participate in the conferences and writing the peer reviewed paper. Finally, he will present the software in the school/workshop with some test cases.

Mrs Vassiliki Krey is a new doctoral candidate who deals with the satellite systems and data processing. She has experience in DORIS system data processing as it was part of her diploma thesis. She will mainly participate in the development of the software package. She will participate in code development and its validation. She will also take part in data processing and time series analysis. Finally, she will take part in conferences and the peer reviewed paper as well as in the preparation, organization and the presentations of school/workshop.

Mr. Vangelis Zacharis is a member of the technical and research staff of Host Institute (NTUA). He has many years of experience in GNSS data processing and code development, and is recently specialized in atmospheric effects on the signal of DORIS satellite system. He will participate in the implementation of the software suites, in testing and evaluating them as well as in data processing.

A MSc or PhD candidate will also participate in the development of the core software suites. She/He will also participate in the processing of the data as well as in the school/workshop that will be organized in the frame of this project.

## Budget

**Table 3.1. Project Budget and justification**

|  |  |
| --- | --- |
| **Cost Category** | **Restrictions** |
| **DIRECT COSTS** |  |
| **Personnel costs1 (PI and Research Team members)** | **150800 €** |
| **Consumables** | **1000 €** |
| **Dissemination and Travel** | **13000 €** |
| **Equipment (Depreciation value)** | **10000 €** |
| **Other costs** | **-** |
| **Subcontracting costs** | **-** |
| **INDIRECT COSTS** | **15200 €** |
| **Total HI Budget** | **190000 €** |

*1For personnel costs please refer to the terms described in Table4 of the call.*

**Budget justification**

Personnel Costs: The largest part of the budget concerns the salaries of the personnel who will work on the implementation of the project. Specifically, the PI and two other members of the Host Institution will receive 23% of the personnel costs. Τhe remaining 77% pertains to the cost of 3 new positions to be created in the project. The two PhD candidates are already working on their Ph.D. thesis on data processing and precisε orbit determination. They will be employed throughout the project mainly in the development of the software and all the necessary algorithms for data processing. They will also participate in the data processing, the organization and participation of the school/workshop and the preparation of the presentations and the article. An new one MSc or PhD student will be involved during half the duration of the project, mainly in the development of the software as well as the data processing.

Consumables: Consumables mainly in technical equipment for the upgrade of computing units as well as for project management.

Dissemination and Travel: Participation to symposiums, etc. for results dissemination. Paper and printing fees for participation to symposium. Travel expenses for attending conferences and working meetings. Εxpenses for the organization of the school/workshop, printed materials, visit to the Dionysos Satellite Observatory where a DORIS antenna is installed.

Equipment: Purchase of three personal computers for the needs of the research group. Also purchase a server for data post processing, estimation of precision orbits, time series analysis and other tasks that require huge computing power.

## REFERENCES

[1] "Jason-3 Satellite - Mission" (https://www.nesdis.noaa.gov/jason-3/mission.html).

Retrieved 10 October 2022.

[2] "Sentinel - Mission Objectives" (https://sentinels.copernicus.eu/web/sentinel/missions/sentinel-3/mission-objectives)

Retrieved 10 October 2022.

[3] "China launches ocean monitoring satellite", Spaceflight Now, October 10, 2022

[4] "National Satellite Ocean Application Service, HY-2C" (http://www.nsoas.org.cn/eng/item/253.html), Retrieved 10 October 2022.

[5] "The International Terrestrial reference Frame: an update", Z. Altamimi, Fifteenth Meeting of the International Committee on Global Navigation Satellite Systems (ICG), 2021

[6] "The international DORIS service contribution to ITRF2020", G. Moreaux, F. G. Lemoine, H. Capdeville, M. Otten, P. Štěpánek, J. Saunier, P. Ferrage, Advances in Space Research, 2022

[7] "Analysis Center Coordinator, IGS Analysis Centers", https://igs.org/acc/, Retrieved 10 October 2022.

[8] "ILRS Analysis Centers", https://ilrs.gsfc.nasa.gov/science/analysisCenters/index.html, Retrieved 10 October 2022.

[9] "Impact of nominal and measured satellite attitude on SLR- and DORIS-derived orbits of Jason satellites and altimetry results", S. Rudenko, J. Zeitlhöfler, M. Bloßfeld and D. Dettmering, Ocean Surface Topography Science Team Meeting (OSTST) 2019, 21-25 October 2019, Chicago, Illinois, United States of America

[10] "DORIS results on Precise Orbit Determination and on geocenter and scale solutions from CNES/CLS IDS Analysis Center contribution to the ITRF2020", H. Capdeville, J-M. Lemoine, A. Mezerette and G. Moreaux, EGU21-5384, G2 - Reference Frames and Geodetic Observing Systems, G2.4 - Precise Orbit Determination for Geodesy and Earth Science

[11] "IDS Recommendations and suggestions for ITRF 2020 reprocessing", International DORIS Service, https://ids-doris.org/images/IDS\_RecommendationsITRF2020\_04.02.2020.pdf, Retrieved 10 October 2022.

[12] "RINEX DORIS 3.0 (Issue 1.7)", CNES & IDS, ftp://ftp.ids-doris.org/pub/ids/data/RINEX\_DORIS.pdf, Retrieved 10 October 2022.

[13] "IERS Conventions (2010)", G. Petit and B. Luzum (eds.), International Earth Rotation and Reference Systems Service (IERS), IERS Technical Note No. 36, 2010

[14] "CNES/GRGS RL04 Earth gravity field models, from GRACE and SLR data. GFZ Data Services", Lemoine J-M.l, Biancale R., Reinquin F., Bourgogne S., Gégout P. (2019), https://doi.org/10.5880/ICGEM.2019.010

[15] "FES2014 global ocean tide atlas: design and performance", F. H. Lyard, D. J. Allain, M. Cancet, L. Carrère, and N. Picot, Ocean Sci., 17, 615–649, https://doi.org/10.5194/os-17-615-2021, 2021

[16] "More constexpr for <cmath> and <complex>", E. J. Rosten, O. J. Rosten, Programming Language C++, Library Working Group, 2019 (available at https://www.open-std.org/jtc1/sc22/wg21/docs/papers/2019/p1383r0.pdf)

[17] Docker, https://www.docker.com/

[18] "Designing a DORIS processing software for orbit determination and estimation of geodetic parameters", X. Papanikolaou, M. Tsakiri, S. Nahmani and A. Pollet, Reference Frames for Applications in Geosciences (REFAG), Thessaloniki-Greece, 2022

[19] "Precise orbit determination and station position estimation using DORIS RINEX data", J.-M. Lemoine, H. Capdeville, L. Soudarin, Advances in Space Research 58 (2016) 2677–2690

[20] "DORIS satellites models implemented in POE processing", L. Cerri, A. Couhert, P. Ferrage, CNES & IDS, 2022

[21] "Implementation of Gauss-Jackson Integration for Orbit Propagation", M. M. Berry and L. M. Healy, The Journal of the Astronautical Sciences, Vol. 52, No. 3, July–September 2004

[22] "Real-time orbit determination of Low Earth orbit satellite based on RINEX/DORIS 3.0 phase data and spaceborne GPS data", C. Zhou, S. Zhong, B. Peng, J. Ou, J. Zhang, R. Chen, Advances in Space Research, Volume 66, Issue 7, 2020

[23] "Estimation of the Length of Day (LOD) from DORIS observations", P. Štěpánek, U. Hugentobler, M. Buday, V. Filler, Advances in Space Research 62 (2018) 370–382

[24] "Development of an in-house DORIS processing software", X. Papanikolaou, V. Zacharis, M. Tsichlaki, S. Nahmani, A.Pollet, M. Tsakiri, J. Galanis, IDS Analysis Center Workshop, Venice-Italy, 2022

[25] "Validating DORIS meteo data", V. Zacharis, M. Tsichlaki, X. Papanikolaou, M. Tsakiri, IDS Analysis Center Workshop, Venice-Italy, 2022

[26] "Routine Analysis of all available GNSS Stations in Greece: Processing Scheme and Dissemination of Products and Data", X. Papanikolaou, D. Anastasiou, A. Marinou, V. Zacharis, D. Paradissis, EGU General Assembly Conference, 2015

1. Please add one of the following types:

   **R** = Report (document, including interim and final report)

   **DEM** = Demonstrator (prototype, plan, etc.)

   **DEC** = Publications, patents, etc.

   **Other** [↑](#footnote-ref-1)
2. Please add one of the following types:

   **PU** = PUBLIC (public available)

   **CO** = CONFIDENTIAL (available only to the research team and H.F.R.I.) [↑](#footnote-ref-2)
3. *Please add the respective Project’s delivery month.* [↑](#footnote-ref-3)